Valuation and Aspirations for Drip Irrigation in Punjab, Pakistan

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Abstract: Modern drip-irrigation technologies improve water-use efficiency while simultaneously transforming areas that are not otherwise irrigable in practice (too distant or too high to be reached by surface waters). Although drip irrigation is expanding rapidly in India, adoption remains low in neighboring Pakistan. To gain deeper insight into the factors constraining adoption of drip irrigation in Pakistan, a discrete choice experiment framed around the hypothetical subsidized purchase of a drip-irrigation system in four districts within Pakistan's Punjab Province was used. The results show higher valuation of drip systems among new users, which suggests that limited technical support and upstream maintenance facilities are not posing significant barriers to drip-irrigation adoption. It was observed that aspirations for cropping systems under drip were better predictors of farmers' valuation for drip systems than current cropping patterns, implying that a different agricultural landscape might reasonably emerge under more widespread adoption of drip. Both aspirations were observed for high-value crops such as fruits, as well as lower-value crops such as wheat, under drip systems, suggesting a number of ways through which drip irrigation may transform Pakistan's agricultural landscape. **DOI: 10.1061/(ASCE)WR.1943-5452.0001181.**

Introduction

Productive use of scarce water is increasingly critical for South Asia (e.g., Barker and Molle 2004; Bengali 2009; Rasul 2014), where massive public-funded irrigation systems consume on average more than 90% (World Bank 2015) of surface water supplies, whose future is increasingly uncertain as rainfall, glacier-melt, and snowmelt shift under climatic changes (Archer et al. 2010; Hewitt 2011; Hosterman et al. 2012; Immerzeel et al. 2009). Modern drip-irrigation technologies can not only improve water-use efficiency in currently irrigated areas [by targeted delivery to crop root zones and reduced conveyance, distribution, and evaporative losses (Narayanamoorthy 2008)], but can also further expand water and land productivity by enabling transitions to higher-value crops or transforming areas that are not otherwise irrigable (too distant or too high to be reached by surface waters).

In India, where drip irrigation is expanding rapidly, savings in water and electricity costs at the farm scale have been consistently found in analyses on sugar (Narayanamoorthy 2005), grapes, cotton, and bananas (Narayanamoorthy 2010; Suresh Kumar and Palanisami 2011). For example, drip-irrigation systems were reportedly installed on 55,000 ha in 1994 (Sivanappan 1994), 246,000 ha in 1998 (Narayanamoorthy 2004), and 650,000 ha by 2013 (Chandrakanth et al. 2013). Despite high installation costs, the cost benefit ratios of drip investments range from 1.7 to 2, depending on the crops and availability of subsidies.

Improved water productivity at the farm scale from drip systems can contribute to a range of policy objectives at the landscape scale. Appropriate policy instruments that either limit global water access or (via water-user fees or the potential for trade) make water more valuable elsewhere (Tiwari and Dinar 2000) can translate the efficiency gains from tools like drip system improvements into global water-use efficiency improvements. In the absence of such instruments, the higher water productivity can create a Jevons paradox of higher overall water consumption (Berbel and Mateos 2014; Dumont et al. 2013), but increasing overall water consumption can also often be a goal of policy. Where water (as opposed to land or other inputs) is physically or economically scarce and limiting, improved water productivity can bring nonirrigated land into production or shift planting toward higher-value cropping patterns (e.g., Batchelor et al. 2014). In short, even where tools like drip systems improve water productivity for the farmer, the landscape outcomes (e.g., reduced consumption, improved environmental flows, or increased production) will depend on the policy context into which they are placed.

For Pakistan, goals for water use in agriculture include both increased efficiency and productivity. Vision 2025, the development framework put forward by the Ministry of Planning, Development, and Reform, calls for investment "in proven methods and technologies to minimize wastage (e.g., in the agricultural sector)" and to "improve efficiency of usage in agriculture by 20 [percent]" in the coming decade (Planning Commission 2014). The Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP), begun in 2012 with support from the World Bank, has the explicit goal to "improve water productivity," contributing to "increased agricultural production, employment and incomes" (Punjab Agriculture Department 2011a). Given these priorities, the observed farm-scale benefits and the rapid expansion of drip systems in climatically

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similar areas in India, the persistently low levels of adoption in Pakistan—where seasonal costs for pumping groundwater can measure in the hundreds of USD per acre (Bell et al. 2014)—are something of a puzzle.

The International Food Policy Research Institute's (IFPRI) 2012 Rural Household Survey (covering 942 households across 76 sampling units that are representative of the provinces of Sindh, Punjab, and Khyber Pakhtunkhwa) (IFPRI and IDS 2015) did not encounter a single farmer using a drip-irrigation system, suggesting that adoption rates are not likely any greater than 1%–2% of rural households and raising the question of what factors could be constraining them. In other regions, constraints have included high up-front capital investment costs and risks associated with operation (e.g., due to poor quality equipment), as well as a lack of knowledge about the systems and crops they can be applied to (e.g., Dai et al. 2015). Structurally, it would be helpful to understand whether the lack of drip-irrigation systems in use is better explained by such upfront barriers preventing initial adoption, or by challenges in using and maintaining drip systems hindering their sustained use by early adopters. Diagnosing this would require data spanning farms with no, little, and moderate experience with drip systems. A key challenge to such analysis would be identifying such a diverse population in a landscape where adoption is known to be very low.

PIPIP is currently the leading example of an instrument that has had some modicum of success in enhancing adoption (Punjab Agriculture Department 2011a), and it may provide the critical frame to identify and examine drip users. PIPIP aims to install drip-irrigation systems on 48,563 ha (approximately 120,000 acres), with cost sharing to reduce the capital burden and incentivize adoption. Specifically, the government covers 60% of the cost of installation through a subsidy paid directly to select service providers (registered with the government to install drip-irrigation systems) who are bound to subsequently provide after-sale technical and maintenance support to farmers on an as-needed basis for up to 2 years. Eventually, PIPIP aims to trigger upscaling by the local private sector, thus improving access to technical support and reducing capital investment costs. Through December 2015, PIPIP had subsidized 8,900 ha (approximately 22,000 acres) of drip systems installation across Pakistan's Punjab Province (World Bank 2016), although to date, there has been very little published in the scientific literature to examine how the factors shaping adoption in Pakistan compared with India, or other contexts where drip irrigation has provided productivity and efficiency gains in dry environments, such as Australia (Mushtaq et al. 2013) or China (Burnham et al. 2015; Dai et al. 2015). With beneficiaries of PIPIP located across a range of agroecological conditions, and with some of these beneficiaries now having several years of experience and new users continuing to join the program, PIPIP provides an ideal backdrop for a rigorous evaluation of the factors shaping perceptions and constraining adoption of drip-irrigation systems.

This study contributes to an underdeveloped literature on drip-irrigation adoption by introducing a discrete choice experiment (DCE) across adopters and nonadopters in four districts of Punjab Province. The DCE is designed to diagnose the structure of the adoption problem in Pakistan, and to assess farmers' aspirations for cultivation that could be realized under the availability of drip systems, through the lens of the current PIPIP regime. Specifically, this study examines how participants with different levels of drip experience value various aspects of a hypothetical drip-irrigation system, described by the amount of farmland covered, the overall cost of installation, the subsidy provided, and periods of knowledge and maintenance support (mirroring the attributes of PIPIP). This study provides a baseline assessment of drip system valuation, against which future (longitudinal) studies can assess changes in valuation over time. An increased valuation by users with increased exposure to drip systems could indicate a knowledge gap because such a result could imply that nonusers are less aware of benefits that can accrue from the use of drip irrigation. In contrast, decreased valuation with experience could indicate a support or maintenance gap because such a result could reflect the difficulties in using drip systems becoming clearer with use.

To foreshadow the obtained results, it was broadly found that utility for drip irrigation is higher among those with at least some drip experience, potentially suggesting an upfront knowledge gap as an important barrier to drip adoption. Encouraging drip adoption through subsidies is likely to accelerate adoption of drip-irrigation systems, but doing so entails weighing the benefits of more widespread adoption of drip against the fiscal burden of distributing large subsidies. An additional key result is that stated aspirations for cropping under a drip system are better predictors of the utility of drip than are current practices. In other words, farming system aspirations under drip differ from those under current systems, and in some parts of Punjab, the promotion of drip could be expected to be truly transformative of the agricultural landscape.

Empirical Methods and Experimental Design

DCEs are a form of stated choice experiment where preferences are elicited based on responses to hypothetical scenarios rather than observed decisions. Although these methods were originally developed to address questions in the marketing and transportation literature (e.g., Louviere and Hensher 1982; Louviere 1988, 1992), they have been increasingly adapted and applied to other sectors, such as environment, health, and agriculture (Bennett and Birol 2010). Across all these disparate applications, choice experiments are particularly useful for studying preferences when functional markets are sparse or nonexistent, or when it may be beneficial to consider implications of multidimensional policy changes (Louviere et al. 2000). In a DCE, individuals are presented a series of hypothetical choice scenarios, in which they must choose between bundles containing different traits (in this case, different characteristics of a drip-irrigation system), where each trait takes one of a number of prespecified levels (i.e., the expression of the trait). Through statistical analysis of participants' choices given the alternatives available in each choice scenario, the researcher can estimate preferences for the incremental changes in the various attributes embodied in the alternatives.

Discrete Choice Experiment Methodology

In discrete choice analysis, it is generally assumed that observed choices arise from utility-maximizing behavior (McFadden 1974; Manski 1977). Specifically, it is assumed that the choices that individuals make, on average, provide the greatest utility among the potential available alternatives. DCEs, the empirical tool employed in the present study, are a widely used form of choice analysis that allows for the elicitation of preferences in an experimental setting. The underlying choice theory can be described as follows. Suppose that individual i faces J alternatives contained in a particular choice scenario t. The latent variable v^*_{ijt} denotes the utility that individual i derives from choosing alternative $j \in J$ in choice scenario t. Utility consists of both a systematic component and a stochastic component. The systematic component reflects individual tastes and preferences that map product characteristics (or attributes) directly into utility. In the present study, in which the product is a drip-irrigation system, product characteristics could include the installation costs and coverage area, among others. The actual characteristics explored in the present study will be described in greater detail subsequently. The stochastic component reflects unobserved, idiosyncratic variations in taste and errors in optimization. Utility can therefore be expressed

$$v^*_{\text{ijt}} = \mathbf{x}'_{\text{ijt}}\boldsymbol{\beta}_i + \varepsilon_{\text{ijt}} \quad (1)$$

where $\mathbf{x}_{\text{ijt}}$ is the vector of irrigation system characteristics observed by individual i within alternative j during choice scenario t; $\boldsymbol{\beta}_i$ is a vector of individual-specific preferences or taste parameters; and ε_{ijt} = stochastic component of utility, which is assumed to be independent and identically distributed across individuals and alternatives.

Each element in the preference vector represents the additional utility that would be derived from an incremental change in the expression of a particular characteristic (e.g., an incremental increase in the installation cost). Consequently, the vector $\boldsymbol{\beta}_i$ can be interpreted as a vector of marginal utilities. Rather than simply estimating the mean level of preferences in the sample, heterogeneous preferences are allowed, and it is assumed that individual preferences are randomly distributed in the population.

Although one cannot directly observe the vector of utilities, one can observe the sequence of choices that the individual makes during the T choice scenarios. Let this sequence be denoted $y_i = (y_{i1}, \ldots, y_{iT})$, where y_{it} is the observed choice, which is assumed to be the choice that maximizes individual i's utility during choice scenario t. With these observed choices, one can estimate the probability that a particular vector of preferences would yield the observed choice. The conditional probability of the observed sequence is estimated by integrating over the distribution of possible preference vectors

$$P(y_i|\mathbf{x}'_{i1t}, \mathbf{x}'_{i2t}, \ldots, \mathbf{x}'_{iJt}, \boldsymbol{\Omega}) = \int \frac{\exp(\mathbf{x}'_{it}\boldsymbol{\beta}_i)}{\sum_{q=1}^{Q}\exp(\mathbf{x}'_{iqt}\boldsymbol{\beta}_i)} f(\boldsymbol{\beta}|\boldsymbol{\Omega})d\boldsymbol{\beta} \quad (2)$$

where $\mathbf{x}_{ijt}$, $\boldsymbol{\beta}_i$, and y_i are as defined previously; and $\boldsymbol{\Omega}$ is a vector of parameters characterizing the distributions of the $\boldsymbol{\beta}$s (e.g., means and variances for normally distributed random parameters). In the choice modeling literature, this is referred to as the mixed logit model (Revelt and Train 1998; Train 2003), which can be estimated by simulated maximum likelihood.

Estimating Eq. (2) yields a series of posterior estimates corresponding to the central tendency (e.g., mean) and dispersion (e.g., variance) of the taste parameters' distributions. Following standard practice, it is assumed that most of the preferences are distributed normally in the population. For the monetary attributes (gross installation cost and subsidy), this study follows Ward and Makhija (2018) and assumes that preferences take a one-sided triangular distribution in the population. The one-sided triangular distribution has the advantage that it maintains the general characteristics of a normal distribution while also imposing restrictions to maintain consistency with economic theory (specifically, a nonpositive marginal utility of cost and a nonnegative marginal utility of income).

Specification of Utility Function and Experimental Design

To operationalize the choice experiment method, the underlying utility function that would be modeled had to be specified as a function of various attributes of a drip-irrigation system. Only once this utility function is specified can one proceed with designing the actual choice experiment to implement in the field. The attributes included in the choice analysis consist of various components that are characteristic of the drip-irrigation systems being promoted under PIPIP, specifically (1) the area covered by the drip system, (2) gross installation cost, (3) subsidy offered to offset the capital costs associated with installation, and the amount (in years) of (4) knowledge support, and (5) maintenance support provided.

The utility function on which the present experimental design is based is a linear (in parameters) utility function that consists of all main effects plus a series of key two-way interactions. The utility function can be written

$$v^*_{\text{ijt}} = \beta_{i1}A_{\text{ijt}} + \beta_{i2}C_{\text{ijt}} + \beta_{i3}S_{\text{ijt}} + \beta_{i4}K_{\text{ijt}} + \beta_{i5}M_{\text{ijt}} + \beta_{i6}A_{\text{ijt}} \times C_{\text{ijt}} + \beta_{i7}A_{\text{ijt}} \times S_{\text{ijt}} + \beta_{i8}C_{\text{ijt}} \times S_{\text{ijt}} + \varepsilon_{\text{ijt}} \quad (3)$$

where A_{ijt} = coverage area of the installed drip-irrigation system; C_{ijt} = gross installation cost; S_{ijt} = subsidy amount; K_{ijt} = years of knowledge support offered; and M_{ijt} = years of maintenance support included in a given package. The approach allowed for the utility of the status quo option to differ from the utility of the hypothetical drip scenarios. This was accomplished by including interaction terms consisting of an alternative-specific constant (ASC) associated with the status quo (ASC_{SQ}) alternative and two individual-specific variables, specifically farm size and a binary indicator variable equal to one if the participant had a drip-irrigation system installed at the time of their interview.

For the attributes included as main-only effects (i.e., not interacted with other attributes, namely knowledge support and maintenance support), the marginal utilities are straightforward: $\text{MU}_{i,K} = \beta_{i4}$ and $\text{MU}_{i,M} = \beta_{i5}$. If interested in estimating, for example, the marginal utility of coverage area, the main effect given by β_{i1} is needed, but also interactions between coverage area and the gross installation cost as well as the subsidy must be reflected. In this case, the marginal utility of coverage area would be simply $\text{MU}_{i,A} = \beta_{i1} + \beta_{i6}C_i + \beta_{i7}S_i$. The marginal utilities for the gross installation cost and the subsidy can be computed in a similar fashion, taking into account both main effects as well as interactions: $\text{MU}_{i,C} = \beta_{i2} + \beta_{i6}A_i + \beta_{i8}S_i$ and $\text{MU}_{i,S} = \beta_{i3} + \beta_{i7}A_i + \beta_{i8}C_i$. These marginal utilities can be evaluated at exogenously determined levels to, for example, evaluate how the marginal utility of a subsidy changes when applied to different coverage areas.

After specifying utility as a function of the aforementioned attributes with the aforementioned functional form, a series of levels were then specified such that each of these attributes would be allowed to take during the actual implementation of the experiment. The gross installation cost levels were chosen to bound the actual per-acre costs estimated within PIPIP both above and below, and farm coverage and subsidy were allowed to span from 0% to 100% of the actual farm area and total cost, respectively. The per-acre installation costs under PIPIP vary with scale and intended use, from around 50,000 to 130,000 Pakistani rupees (PKR) per acre (Punjab Agricultural Department 2011b). Drip-irrigation systems promoted under PIPIP cover up to a maximum of 8 ha (approximately 20 acres), with subsidies currently set to 60% of the total cost.

Under the PIPIP project, there is a significant oversight and financial role of the provincial government. The On-Farm Water Management (OFWM) Wing in the Punjab Agricultural Department invites applications from interested farmers and sends an approved supply company to survey the potential site. They collect 40% of the costs as the farmer's share and appoint a consultant to design the system, after which the supply company installs the drip system on the farmer's site and receives the payment (Punjab Agricultural Department 2017). Knowledge and maintenance support levels were bounded from 0 years (i.e., no support) up to the 2 years provided in the PIPIP to capture the presence/absence of follow-up support.

Table 1. Choice experiment attributes and levels

Attribute	Levels
Coverage area (percent of total farm area)	0; 20; 40; 60; 80; 100
Gross installation cost (PKR)	30,000; 60,000; 90,000; 120,000; 150,000
Subsidy amount (percent of gross installation cost)	0; 20; 40; 60; 80; 100
Knowledge support (years)	0; 1; 2
Maintenance support (years)	0; 1; 2

When designing the experiment, the coverage area was specified as a percentage of the total area of the farm, gross installation cost in PKR, the subsidy as a percentage of gross installation cost, and knowledge and maintenance support in years. When the choice scenarios were presented to farmers, the coverage area was converted to acres (based on the farmer's self-reported land ownership) and the subsidy amount was converted to PKR (based on a calculation using the gross installation cost for the specific alternative). These calculations were done by embedding simple computations into the computer-assisted personal interviewing (CAPI) technology used for the survey.

A summary of the choice experiment attributes and their corresponding levels from the base specification is reported in Table 1. Although the coverage area and subsidy are here specified as percentages, the actual choice alternatives presented to respondents converted these figures into acreage or PKR, based upon the farmer's total land area (in the case of coverage area) and the gross installation cost specific to the alternative (in the case of the subsidy). The source of any subsidy is not specified as part of the experiment, although at the time of the experiment the prevailing source of drip system subsidies was the PIPIP program. Knowledge and maintenance support is described in years of access, with no further constraint on how often or to what degree these support mechanisms can be accessed. Under PIPIP, the supply company that installs the system must provide maintenance as well as knowledge training for 2 years, and 10% of the total payment is kept in the OFWM to address problems after installation for 2 years (Punjab Agricultural Department 2017).

Translating these attributes and levels into an experimental design that can be implemented in the field requires trading off the number of alternatives in each choice set and the number of choice sets to which respondents will be asked to respond. In a single discrete choice scenario with more than two alternatives, researchers are only able to observe weakly ordered preferences because a single discrete choice provides incomplete information on the preference orderings over the entire universe of potential choices. In order to accumulate a more complete picture of preference orderings, the researcher must either increase the number of choices observed by an individual, or increase the number of individuals for whom choices are observed under a wider range of attributes (Louviere et al. 2000). Although either option can identify preference orderings, incorporating both improves identification to an even greater extent. In so doing, however, one must undertake some specific considerations because the experimental design has important implications for the efficiency of parameter estimation.

The experimental design involves varying levels of the package attributes to satisfy a well-defined statistical criterion [e.g., D-efficiency (e.g., Bliemer and Rose 2005; Scarpa and Rose 2008; Carson and Louviere 2010)]. D-efficiency is an experimental design criteria that is satisfied when an experimental design minimizes the D-error, which is computed as scaled determinant of asymptotic variance-covariance matrix of the design. The experimental design used in this study was generated using a custom-designed script in R (version 3.5.1) that allowed the authors to specifically weed out any bad designs, namely those with clearly dominant choice alternatives. The ultimate experimental design used informative priors taken from parameter estimates based on pretest data, which were themselves based upon an experimental design assuming null priors (that is, assuming the preference parameters were all zero). The design generated 30 unique choice sets, which were randomly assigned to farmers in groups of six choice sets each, with each choice set assigned an average of 92 times (minimum 80 and maximum 107).

This is distinct from a blocked experimental design because the set of choice sets that is randomly assigned to each respondent is potentially unique for each individual. In other words, the computer routine used to allocate choice sets to respondents would randomly select six choice sets from the original pool of 30 choice sets without replacement. Thus, any unique combination of six choice sets has odds of 1 in 593,775 of being allocated. Each choice set contained three hypothetical alternatives consisting of the aforementioned drip system attributes as well as a status quo option (i.e., the production practices used in the most recent agricultural season).

Measuring Aspirations

In every choice task for which the respondent selected one of the hypothetical alternatives, they were asked to carefully consider whether they would change any of their current cropping patterns given the new high-efficiency input selected. They were not asked for numerical estimates of how much cropping area they would change, but rather simply asked whether they would plant more or less of any particular crops (or perhaps entirely different crops than were currently being planted). Assessing aspirations is a relatively new area of research (Kosec et al. 2012), with current approaches divided among those that assess respondents' agreement with hypothetical conditions or maxims, such as "Each person is primarily responsible for his/her success or failure in life" (Bernard et al. 2012), and those that ask respondents directly about their desires for income, education, or their children's futures (e.g., Beaman et al. 2012; Kosec et al. 2012). The used approach borrows more from this latter approach, although the focus is very narrowly on aspirations for cropping patterns rather than other aspects of rural livelihoods, and thus different measures of aspirations are not drawn together in any kind of composite index. The only interpretation among aspirations is to distinguish those that lie along the extensive margin (i.e., those who aspire only for more of some crop) versus those along the intensive margin (i.e., those who aspire for more of some crop with less of some other crop).

Data Sources

The data used in this study come from a household survey conducted among 475 households across four districts (Attock, Chakwal, Layyah, and Sahiwal) in Punjab Province, Pakistan (Fig. 1). These districts capture contrasting agroecological zones (FAO 2004) and contrasting agricultural systems. Chakwal and Attock are predominantly rainfed areas, with some parts of Attock relying on groundwater use; Layyah is considered sandy desert, with low rainfall and poor access to canal infrastructure; Sahiwal sits within the irrigated Indus floodplain (Table 2).

Several features of the agricultural sector in Punjab affect outcomes and interpretations in this analysis. Of total cropped area, 42% in Punjab is in wheat, but in the winter (rabi) season, it is by far the major crop grown, with over 90% of acreage (Punjab Agricultural Department 2016). This is also the season with the lowest flows in the canal system and the least rainfall. Therefore, the

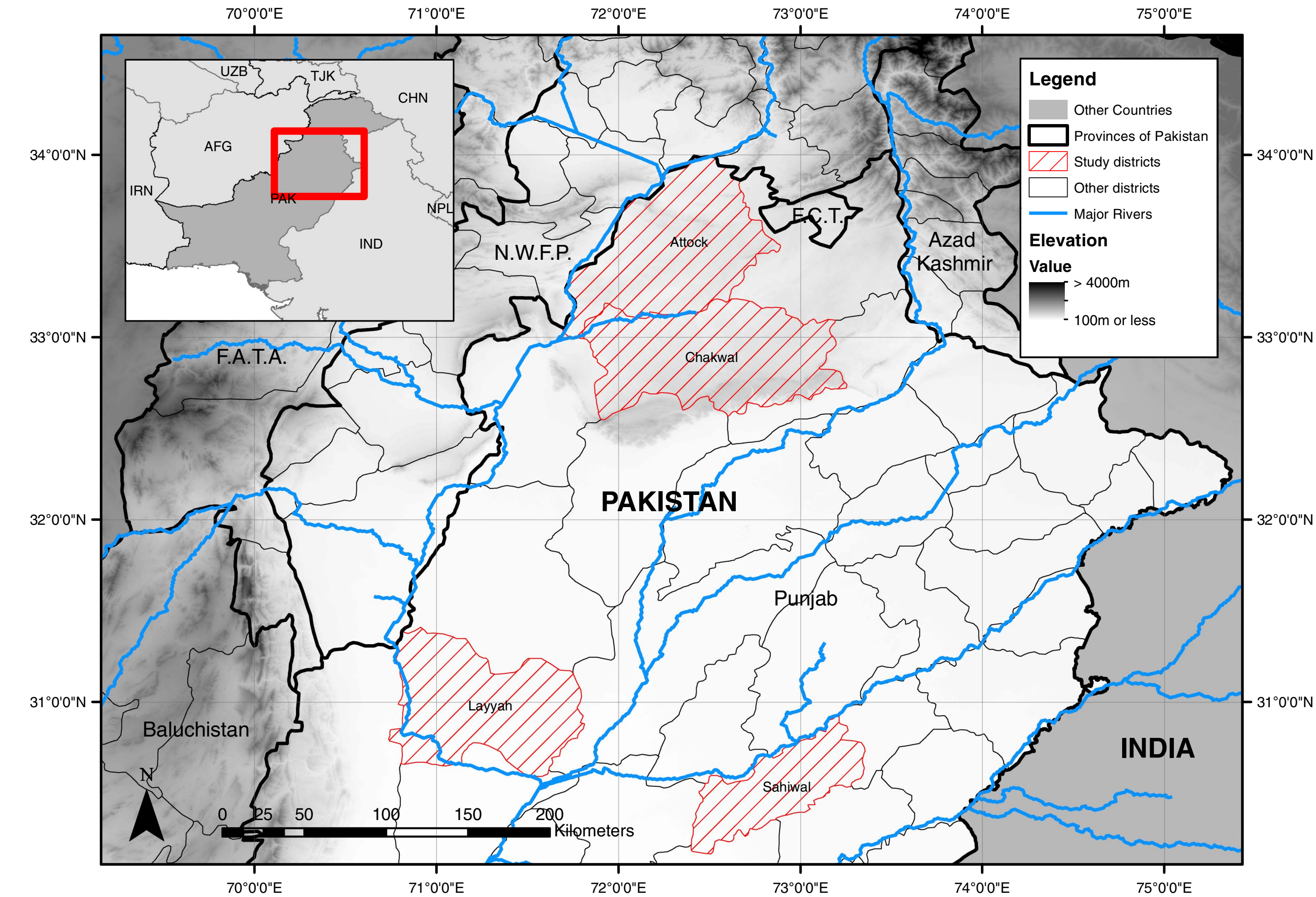

Fig. 1. Map of study districts.

Table 2. Water sources accessed (percent of farmers), disaggregated by district

District	Rain	Borehole	Well	Canal
Attock ($n = 158$)	0.494	0.266	0.373	0
Chakwal ($n = 65$)	0.723	0.354	0	0
Layyah ($n = 86$)	0.047	0.430	0.442	0.151
Sahiwal ($n = 131$)	0	0.076	0.244	0.687
Total	0.293	0.255	0.293	0.234

choice of how much acreage to plant, especially in wheat, and given uncertainty about water, is of concern to most farmers during rabi season. In 2018, for example, the government announced an expected reduction in canal water of 45% in nonperennial canals, which serve approximately one-third of the irrigated acreage (Hasan 2018). This concern is exacerbated in rainfed districts such as Chakwal and Attock.

The long-term availability of water, along with a proximity to population centers and transport systems, have also affected market access, and likely the respondent's aspirations in each district. Although all districts have central markets, with buyers and wholesalers participating, these will not have sufficient volumes of higher-valued products in areas with less varied production. Therefore, with a small diversity in production, the development of sufficient opportunities for high-valued products is not easy, and the aspirations for change could be muted. In contrast, in Sahiwal, there is a well-developed potato marketing and storage system, with sales across the country and to exports, and a strong trade association and access to improved technologies, so farmers there have seen successes. Finally, a major wheat procurement program has existed for many years, and larger farmers, such as those in this program, can make use of it. Currently, the prices in this program exceed international ones by over 25%, so in effect, this creates a barrier to shifting to production of higher-valued commodities.

In designing the sampling frame, one of the authors' primary interests was to capture a gradient of drip-irrigation experience and exposure. Because current rates of drip-irrigation adoption are very low, any sort of random sampling (e.g., simple, stratified, or clustered) was unlikely to provide enough observations to reasonably estimate preferences among current drip users with any degree of precision. To circumvent this issue, this study's sampling design purposively oversampled existing drip users. First, rosters of farmers receiving a subsidy under PIPIP in the sample districts were obtained. Attempts were made to contact all individuals on these lists to secure participation in the survey, with modest success, obtaining interviews from 237 respondents across the four districts. Where the authors were successful in engaging current drip users, the users were asked to identify another farmer in their village who was very similar to them (in terms of cropping patterns, farm size, and socioeconomic status, for example), but who, crucially, was not a current drip-irrigation user. These nominated farmers were subsequently interviewed, doubling the number respondents to a total sample of 475 farmers.

Table 3. Summary statistics of farm households in our sample, disaggregated by drip-irrigation usage status

	Users		Nonusers		Overall	
Characteristic	Mean	Standard error	Mean	Standard error	Mean	Standard error
Age (years)	45.579	0.851	45.758	0.722	45.696	0.556
Female household head (=1)	0.012	0.009	0.010	0.006	0.011	0.005
Formal education (highest class)	11.018	0.451	7.981	0.283	9.029	0.251
No. of female household members	2.030	0.108	2.183	0.086	2.131	0.067
No. of male household members	2.378	0.088	2.842	0.090	2.682	0.067
Farm size (acres)	18.839	2.259	12.608	1.230	14.760	1.128
Cultivates: cereals (=1)	0.415	0.039	0.854	0.020	0.700	0.021
Cultivates: vegetables and melons (=1)	0.085	0.022	0.003	0.003	0.032	0.008
Cultivates: fruits and nuts (=1)	0.793	0.032	0.070	0.015	0.324	0.022
Cultivates: oilseeds (=1)	0.012	0.009	0.036	0.011	0.028	0.008
Cultivates: fiber crops (=1)	0.098	0.023	0.325	0.027	0.245	0.020
Fallowed because of lack of water (=1)	0.293	0.036	0.241	0.024	0.259	0.020
Fallowed because of cost or electricity constraint (=1)	—	—	0.605	0.028	0.396	0.022
Primary irrigation: canal	0.079	0.021	0.312	0.026	0.232	0.019
Primary irrigation: rainfall	0.226	0.033	0.315	0.026	0.284	0.021
Primary irrigation: well	0.317	0.036	0.260	0.025	0.280	0.021
Primary irrigation: borehole	0.488	0.039	0.122	0.019	0.248	0.020
Groundwater cost: nonuser	—	—	1.280	0.165	0.829	0.111
Groundwater cost: new user	1.613	0.204	—	—	0.685	0.080
Groundwater cost: old user	0.848	0.156	—	—	0.299	0.058
Reliability of canal (percent of time surface water supply is delivered as expected)	5.838	1.659	21.921	2.005	16.368	1.474
District: Attock (=1)	0.470	0.039	0.264	0.025	0.335	0.022
District: Chakwal (=1)	0.244	0.034	0.129	0.019	0.168	0.017
District: Layyah (=1)	0.220	0.032	0.193	0.022	0.202	0.018

In some cases, farmers who were identified as having received subsidies had not in fact followed through with using drip systems, either because they were incorrectly listed as an adopter or because they actually purchased a system and paid the net cost but do not currently use it. Thus, the resulting sample consists of 164 current users and 311 nonusers, among whom 296 never used drip and 14 that had, at some point, used drip, but were currently not using the technology at the time of the interview. Of the current users, most were relatively new adopters. Roughly 63% of current drip users had fewer than 3 years of experience with these systems, whereas only 3% had more than 5 years of experience. Although the sample is not representative (due to oversampling drip adopters and consisting of larger farmers), the sample is arguably reflective of farmers who are most relevant for PIPIP and other such programs promoting drip irrigation. Importantly, it is a single-period sample, and although the level of experience with drip as controlled for, endogeneity or selection bias owing to farmers' original decision to adopt cannot be resolved.

Basic summary statistics for the households included in our sample are reported in Table 3. Detailed summary statistics, including basic household demographic and agricultural characteristics, experiences with (for current drip users) and perceptions of (for nonusers) drip-irrigation systems (including gross installation costs per acre, subsidy per acre, and support provided), and information on current cropping patterns are provided in Tables S1–S3.

Results

The results are presented in five parts. First, the results from the estimation of the overall utility function via the mixed logit model introduced in Eq. (2) are presented. Second, the estimated marginal utilities on cost and subsidies, along with results of two additional embedded experiments, are drawn upon to identify the appropriate income measure for estimating willingness to pay (WTP). Third, this model structure is applied to estimate WTP for installation of a hypothetical drip-irrigation system, across nonusers and current drip users. Fourth, a descriptive analysis of participants' reported aspirations for their land, should they adopt the drip systems presented in the choice scenarios, is presented. Fifth, the aspirations results are integrated with the modeled marginal utilities to examine key explanatory factors in participants' valuation of drip systems using regression analysis.

Utility Model Estimation

The results from estimating the mixed logit model are reported in Table 4. Statistical significance was found for all distribution parameters, which represent the dispersion in the distribution of preferences in the population and provide strong support for the assumption of heterogeneous preferences. The results of the econometric estimation suggest that although respondents do appreciate the technical and maintenance support offered alongside drip installation (evidenced by the positive marginal utility coefficients), these are not weighed heavily when making the decision to adopt drip. Further, the interactions between the ASC (for the status quo option) and farm characteristics suggest that larger farmers are more likely to be interested in installing a drip-irrigation system, and those farmers that already have a drip-irrigation system installed are likely to want to retain their existing drip system. When considering the noisiness of individual decisions across different choice sets, evidence suggests that some respondents ignore these attributes altogether when making decisions. Based on the criterion that a coefficient of variation greater than or equal to 2 suggests that a particular attribute is being ignored (e.g., Hess and Hensher 2010), approximately 20% of respondents ignore the knowledge support component, whereas 33% ignore the maintenance support.

The coefficient estimates reported in Table 4 provide insights into preferences and can be used to ascertain preference orderings, but are difficult to interpret in absolute terms because utility is a noncardinal theoretical construct. To facilitate cardinal interpretations,

Table 4. Mixed logit regression results

Means and distributions of random parameters in utility function	Coefficient	Standard error
Mean: coverage area	0.210***	0.019
Distribution: coverage area	0.324***	0.021
Mean: gross cost of installation (per acre)	−0.243***	0.083
Distribution: gross cost of installation (per acre)	0.243***	0.083
Mean: subsidy (per acre)	1.067***	0.193
Distribution: subsidy (per acre)	1.067***	0.193
Mean: knowledge/technical support	0.469***	0.055
Distribution: knowledge/technical support	0.632***	0.066
Mean: maintenance support	0.362***	0.053
Distribution: maintenance support	0.617***	0.068
Mean: coverage area × subsidy	0.320***	0.022
Distribution: coverage area × subsidy	0.156***	0.014
Mean: coverage area × gross installation cost	−0.273***	0.015
Distribution: coverage area × gross installation cost	0.274***	0.017
Mean: gross installation cost × subsidy	−0.032	0.071
Distribution: gross installation cost × subsidy	0.712***	0.090
Nonrandom parameters in utility		
ASC_{SQ} × farm size	−0.009**	0.004
ASC_{SQ} × has drip	1.201***	0.074
Number of parameters	16	
Number of observations	475	
Log-likelihood	−3057.74125	
Pseudo R^2	0.2246	
Akaike information criterion (AIC)	6,147.5	

Note: *** indicates significant with 1% probability of Type I error; ** indicates significant with 5% probability of Type I error; And ASC_{SQ} = alternative-specific constant pertaining to the status quo option. Both conditional and mixed logit regressions estimated using NLOGIT 5.0. Mixed logit regression estimated based on 1,000 Halton draws for simulated maximum likelihood. Coefficients associated with coverage area, technical support, maintenance support, and attribute interactions assumed to be distributed normally. Coefficients associated with gross installation cost and subsidy assumed to be distributed according to a one-sided triangular distribution, with $\beta_{i,C} = \beta_C + \beta_C \nu_i$ and $\beta_{i,S} = \beta_S + \beta_S \nu_i$, assuming $\beta_C < 0$, $\beta_S > 0$, and $\nu_i \sim \text{Tri}(-1, 1)$.

marginal utilities are converted into monetary terms by taking the ratio of the marginal utility of an attribute with respect to the marginal utility of income.

Cost versus Subsidy to Measure Utility of Income

Because PIPIP offers sizeable subsidies, the effect of subsidies on encouraging drip adoption is of considerable policy import. The analysis provides two different measures of the marginal utility of income, namely via both the cost and subsidy attributes in the DCE. Specifically, because the subsidy is a cash injection whereas the installation cost is a cash outlay, the marginal utility of the subsidy is a direct estimate of the marginal utility of income, whereas the marginal disutility of the gross installation cost (because the marginal utility is negative) is an alternative estimate for the marginal utility of income. In theory, these two measures should be the same, at least to a reasonable approximation.

In the conducted choice experiment, however, it was found that the marginal utility of the subsidy is nearly 4.5 times the marginal disutility of the gross installation cost, suggesting a very different perception of gains from the free money of a subsidy versus the outlays of cash via the cost of drip installation. Additional support for this result was found in additional experiments that were conducted contemporaneous with the choice experiment (not reported here). In one of these additional experiments, a subsidy experiment in which respondents were asked to choose between two alternatives with the same net cost, nearly 84% of respondents selected the alternative that had the larger subsidy, despite it also having higher gross installation costs. The resounding preference for a subsidy—even though there is no real benefit in terms of net financial situation—is beyond that which could realistically occur through random selection.

This study's results suggest that although farmers think about both gross costs and subsidies, they are not especially sensitive to net costs. The coefficient on the interaction of gross installation cost and the subsidy is not statistically significant in Table 4, although the standard deviation of the preference distribution is statistically different from zero. The insignificant mean of the distribution suggests that, on average, the marginal utility of a subsidy is not diminished by higher gross installation costs, nor is the marginal disutility of the gross installation cost offset by higher subsidies. The statistical significance of the distribution suggests that although the average marginal utility is indistinguishable from zero, there is a great deal of heterogeneity in these preferences within this study's sample.

With such a wide variation in preferences, especially relative to an insignificant mean, there is clearly a great deal of noise in these preferences, and thus it leads one to wonder whether the noise is perhaps reflective of respondents ignoring net costs altogether. When considering the noisiness of individual preferences across choice sets, there is strong evidence to suggest that many farmers do not think about the net costs of the drip-irrigation system when making decisions. The noise-to-signal ratio (coefficient of variation), on average, exceeds 12, and over 60% of farmers in the sample have a noise-to-signal ratio greater than 2, which may be interpreted as providing evidence that the respondents ignored the interaction of these two terms, even though the attributes were presented as distinct features of the product bundles and were quite strongly attended to as such. Even if it is assumed that these estimates are not indicative of the farmers ignoring net costs, it seems unlikely that such noisy choices across choice sets could be consistent with rational preference ordering.

Estimating WTP

Following standard conventions (e.g., using product cost as a proxy for the marginal disutility of income), the negative of the gross installation cost is treated as the measure of the marginal utility of income when constructing estimates of WTP. Because the marginal utility of coverage area is a function of the installation cost and subsidy, some assumptions have to be made about the levels of these attributes at which to evaluate the marginal utility. Similarly, the marginal utility of the gross installation cost is a function of the coverage area and the subsidy. Following standard practice, these marginal utilities are evaluated at the means of the observed data.

To estimate the average WTP to have a drip-irrigation system installed, a particular full system of 6 ha (approximately 15 acres) of coverage and 2 years of both technical and maintenance support on the system was assumed, and it was considered that current users already have some or all of this full system in place. The term full WTP is used to mean the amount that individuals would be willing to pay for a movement from no coverage to 6 ha (approximately 15 acres) of coverage, and from no support to 2 years each of technical and maintenance support. The term actual willingness is used to mean the amount that individuals would be willing to pay for a movement from their current coverage to the full system, so the actual WTP for a current drip user will, under most circumstances,

Table 5. Full and actual WTP for drip-irrigation system installation

Valuation	Nondrip users		Current drip users	
	Mean	Standard deviation	Mean	Standard deviation
Full WTP (to go from no drip to full system)	96,246.95	174,558.40	158,469.45	174,558.40
Actual WTP (to go from current system to full system)	—	—	118,884.32	280,353.40

be lower than the full WTP because one would not expect current users to pay for something that they already have.

Table 5 reports estimates for the average full and actual WTP across subsamples of current nonusers and users. In this table, Full WTP represents willingness-to-pay to go from having no system to having a drip-irrigation system installed covering 6 ha (approximately 15 acres) with 2 years knowledge and maintenance support. Actual WTP represents existing drip-irrigation users' willingness-to-pay to go from their current system [covering, on average, 3.7 ha (approximately 9.2 acres), with average knowledge and maintenance support of 1.38 and 1.29 years, respectively] to a drip-irrigation system covering 6 ha (approximately 15 acres) with 2 years knowledge and maintenance support. Under both specifications, it is found that (1) current users have a higher valuation for drip systems (based on Kolmogorov-Smirnov tests against a two-tailed alternative hypothesis, (2) the distributions of full WTP between current drip users and nonusers are statistically different at the 5% level, and (3) the distributions of actual WTP are statistically different at the 10% level.

The estimate of actual WTP suggests that most existing drip users face coverage constraints and would be willing to pay nearly PKR 120,000 for a drip system to cover 6 ha (approximately 15 acres). For these farms, the area on which drip systems are currently installed is less than 4 ha (approximately 10 acres), although their total land holding is closer to 8 ha (approximately 20 acres). This suggests that these farmers clearly understand and appreciate the value of high-efficiency irrigation and would thus be willing to pay a significant amount to increase the area under their existing drip system.

Agricultural Aspirations

Whenever respondents chose one of the hypothetical alternatives in the DCE (as opposed to reverting to their status quo), they were asked to think carefully about what they would plant using the chosen drip option. Using the Food and Agricultural Organization of the United Nations (FAO) crop classification system (FAO 2010), agricultural aspirations were grouped into categories of more or less (1) cereals, (2) vegetables and melons, (3) fruits and nuts, (4) oilseed crops, and (5) beverage and spice crops. In general, most respondents indicated that if they installed a drip-irrigation system, they would expand production, with more fruit and nuts being the most commonly stated aspiration (Table S4). Aspirations differed across districts: fruit and nuts would be the main choice in Attock, Chakwal, and Layyah, with vegetables and melons having some minor importance in Chakwal and Layyah; in Sahiwal, the aspirations are broadly spread across cereals, vegetables and melons, oilseeds, beverage and spice crops, and legumes. These aspirations possibly reflect an intention of expanding production along the extensive margin by bringing uncultivated land into production.

A smaller number of farmers stated aspirations for more of something along with less of something else (in most cases, less cereals, as indicated in Table S5). Most of these respondents were in Sahiwal, possibly demonstrating goals of substituting higher-value for lower-value crops (primarily wheat), thereby showing substitution and improvement of production along the intensive margin.

Participants generally reported the same aspirations in each choice (approximately 80% similarity across any two choice sets, as indicated in Table S6), with the differences across their aspirations weakly correlated with some of the attributes (Table 6). For example, higher subsidy levels are generally correlated with stated aspirations of planting more vegetables and melons.

The clear differences in patterns of aspirations by district are notable because these districts have distinct characteristics (with the exception of neighboring Attock and Chakwal) that represent vastly different agroecological zones, patterns of water sourcing, and current cropping patterns (c.f., Tables 2, S1, and S3). Notably, in Sahiwal (where most farmers rely on canal irrigation and where there is little experience overall with drip) the range of aspirations is broadest, including the introduction of high-value crops [vegetables, melons, and beverage and spice crops (chilies, specifically)] that are essentially nonexistent.

These outcomes are consistent with the previous discussion of variations in water availability and market access. In the three districts with greater water scarcity, it is logical that they choose tree crops that can be added strictly with a drip system and which might not require the more developed processing facilities that other perishables need. Although experience with drip is not prevalent in Sahiwal, knowledge of the extent of market access is likely common, and so farmers might feel more comfortable aspiring to a wider range of products. It cannot be known to what extent a drip

Table 6. Effect of alternative attributes on subsequent agricultural aspirations

Variables	Would grow more cereals	Would grow more vegetables and melons	Would grow more fruits and nuts	Would grow more oilseeds	Would produce more beverages and spices	Would grow less cereals
Constant	−1.085***	−1.141***	−0.210*	−1.723***	−1.242***	−0.670***
Coverage area	−0.00137	0.00260	−0.00237	−0.00297	0.00405	0.000112
Gross installation costs	3.08×10^{-6}**	-4.76×10^{-6}**	7.96×10^{-7}	6.37×10^{-8}	1.69×10^{-6}	-1.49×10^{-5}***
Subsidy	-3.85×10^{-6}***	5.97×10^{-6}***	-1.67×10^{-6}	-1.47×10^{-7}	-1.63×10^{-6}	1.47×10^{-5}***
Knowledge support	−0.142***	−0.0917*	0.0770*	0.0413	0.175***	−0.0337
Maintenance support	0.0389	−0.0799*	0.0364	0.109**	−0.0870*	−0.0879**
Observations	1,720	1,720	1,720	1,720	1,720	1,720

Note: *** indicates significant with 1% probability of Type I error; ** indicates significant with 5% probability of Type I error; * indicates significant with 10% probability of Type I error. Standard errors adjusted for clustering at the district level.

subsidy would truly enable the survey respondents to realize these aspirations, although the data suggest that to the extent that constraints are purely environmental, it might—of the 200 respondents who identified some of their land in fallow, 70% reported lack of water as the reason.

Modeling the Marginal Utilities

The individual-specific marginal utility estimates for each attribute of the drip subsidy are modeled as functions of farmers' location and degree of experience with drip, their demographics and household structure, and their current cropping patterns, as well as stated aspirations for cropping under drip, stated constraints faced in land or adopting drip, and the water source used in cropping. The standard errors are clustered at the level of the respondent (i.e., accounting for correlation across the six choice tasks performed by each individual). These relationships are estimated using ordinary least squares, with the estimated conditional marginal utilities as dependent variables, and the results are reported in Table S7.

First, aspirations for planting (included in all models labeled B) are generally better predictors of a farmer's valuation of attributes than are current cropping choices (included in all models labeled A), indicated by comparing the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for Models A and B for each of coverage, installation cost, and subsidy. The comparison does not hold for marginal utilities for maintenance and knowledge support, which do not appear to be considered strongly alongside the first three attributes in the DCE. Interestingly, aspirations at the extensive margin (captured by the "Would grow more _______" terms) are tied to higher valuation of coverage and higher sensitivity to cost; aspirations at the intensive margin (captured by the "Would substitute _________" terms) link to higher valuation of the subsidy. In the following paragraphs, the presentation of results is based on the models labeled B, including aspirations rather than cropping pattern dummies.

In these regressions, reported in Table S7, drip experience is parsed into three categories of (1) nonuser (0 years of experience with drip), (2) new user (1–2 years of experience with drip), and (3) old user of drip (3 or more years of experience with drip), and experience is interacted with district. The regressions thus include dummy variables for nonusers, new users, and old users for each of Attock, Chakwal, and Layyah (nine terms in total) regressed against a baseline (omitted group) of all users from Sahiwal (where over 90% of respondents have no experience with drip systems). In general, experience with drip increases respondents' valuation of the coverage area of the subsidy, suggesting that with experience, farmers are better able to visualize benefits of installing drip systems on their lands. Valuation of coverage by new and old users is greater than that of nonusers in Chakwal and Layyah; valuation of coverage by old users is greater than that of nonusers in Attock (Table S8). Valuation of coverage among old users is not observed to be greater than that of new users in Attock, Chakwal, or Layyah.

At the same time, the marginal disutility on cost follows a similar pattern, with new and old users generally exhibiting greater sensitivity to the cost of the drip system than nonusers in each of Attock, Chakwal, and Layyah. This pattern indicates that in general, valuation of a drip subsidy program by those with experience with drip systems is more sensitive to increases in the cost, possibly reflecting an improved ability to calibrate the net benefits realizable from installing a drip system (or perhaps an assessment that drip systems would be less valuable in the remaining areas of their farms not currently thus irrigated). Along the same vein, the marginal utility on the subsidy is higher among new users in Chakwal and Layyah than it is among nonusers in the same areas; no differences are observed in Attock. Taken together, these effects on the marginal utilities for coverage, cost, and subsidy suggest a greater awareness of potential benefits from drip systems among those who have experience with them, providing some indication of a current knowledge gap.

A negative relationship is observed between the size of farm holdings and the marginal utilities of coverage area and subsidy (with a weak curvature to the effect on coverage, bottoming out at around 52.6 ha (approximately 130 acres), well above the maximum holding size in this sample), consistent with the notion of higher land-use intensity on smaller farms (Ellis 1993). The implication of this result is that smaller holdings in the sample appear to value both the coverage and the subsidy more highly and thus might be more likely to adopt drip systems.

A clear effect of constraints on drip valuation is also found: those participants who face constraints in watering their fields or paying for/powering drip systems value the coverage and subsidy more highly but are also more sensitive to the cost of the system. Well and borehole users—who would need to pay to pump any water used in the system—are also more sensitive to the cost. This may reflect that such users do not regard a drip system as cost-saving with respect to pumping costs, or that they perceive the up-front cost as possibly constraining their ability to meet any pumping needs in the period thereafter.

Discussion

The principal objective in carrying out this study was to establish a baseline valuation of drip irrigation in the study area by respondents with different socioeconomic characteristics and experience with drip systems, such that further data collection would engender diagnoses of factors constraining adoption through changes in valuation with experience. The baseline findings unambiguously show a higher valuation of the coverage in a program by users with some experience with drip irrigation (compared with nonusers), along with a higher sensitivity to the cost of the program and an increased valuation of the value of the subsidy. No difference is found in the valuation of maintenance support with increased experience, and a lower valuation of knowledge support is observed among those respondents with 1–2 years of experience with drip systems. Taken together, these results are consistent with the narrative that adoption is limited by gaps in knowledge regarding drip—as observed by Dai et al. (2015) in the case of China—as opposed to issues with maintenance or realizing benefits (which a lower valuation with experience would indicate). Again, this study's single round of data collection cannot resolve whether this higher valuation among new users simply means that those who value drip will adopt it, and those who do not value it in turn do not adopt it. However, these initial findings do help to refute the possibility of support or maintenance gaps being constraints on adoption (which a lower valuation among new users would suggest), and they set a foundation for future data collection. If it is in fact the case that those who do (and will) value drip systems highly have already adopted, then the costs of employing drip systems in the future may be progressively more costly to encourage—perhaps an opposing outcome to one in which a spread of shared knowledge among peers leads instead to lower costs of encouragement with time. This is an important question that only a panel-level analysis of the future path of adoption can inform, for which this study provides the first of two (or more) critical pieces. The ongoing promotion of drip systems via PIPIP will hopefully provide just such an opportunity for panel analysis in the years to come.

A second finding is that although some characteristics shaping higher valuation of a drip subsidy program are intuitive, i.e., those facing constraints in access to water, capital, or electricity, there is a counterintuitive lower valuation of drip subsidies by farmers with larger landholdings. PIPIP has explicit adoption targets by land holding size (5,400 units on 3-acre holdings; 5,400 units on 5-acre holdings; 4,800 units on 10-acre holdings; and 1,920 units on 15-acre holdings), and this study's results suggest that it may be more successful in reaching targets for the smaller holdings (or perhaps reaching them earlier).

Finally, this study's results show that aspirations may provide better predictors of valuation (and consequently, the likelihood of adoption) of a drip program than using existing cropping patterns. More specifically, it is observed that aspirations for expanded production along the extensive margin (stating aspirations for more of what they are currently cultivating, specifically more cereals or fruit and nuts) predict higher valuation of coverage area and a greater sensitivity to the cost of the system. In contrast, it is observed that aspirations for increasing production along the intensive margin (stating aspirations to do less of what they are currently cultivating, typically wheat, alongside aspirations to grow more of other products, specifically chilies, fruit and nuts, or oilseeds) predict higher sensitivity to the subsidy. Therefore, increasing the subsidy on drip-irrigation systems could encourage more high-value crop production, such as citrus, as farmers transition out of staple crops such as wheat. In contrast, increasing the areal coverage of the program could do more to encourage expansion of crop cultivation into currently undercropped areas, albeit in ways that might add to cereals production.

It is an open question of whether such aspirations can be reached and whether there are sufficient inputs and supporting market growth to permit this expansion. Although a complex assessment, a recent study by Young et al. (2019), looking at water demand for agriculture and nonagricultural uses in Pakistan, found that as income grows, consumption progressively moves toward more fruits and vegetables. These are commodities that would expand with more drip systems in place, even with slowing fertility, and Young et al. (2019) reported that demand from population growth will rise for all products, including basic cereals. Thus, the respondents' aspirations appear to fit some assessments of the longer-run market outlook.

The fact that most respondents expect to expand on the extensive margin fits likely opportunities. The irrigation system in Pakistan was originally developed to cover subsistence water requirements and typically aimed at a 70% cropping intensity (the number of crops per year per acre), so adding cropped acreage would appear to be possible. This figure is now closer to 100%, only possible using additional groundwater, which often costs up to 10 times that of canal water (Government of Punjab 2015). Drip use will economize on expensive tubewell water to make it less costly. Moreover, the Punjab Government is encouraging water storage facilities via subsidies to raise water availability, which if developed in combination with a drip system, will create improved economic outcomes. In this regard, the gross value of production rises exponentially with cropping intensity, implying another payoff from extending land via a drip system (Tahir and Habib 2000).

More importantly, the linkage from aspirations to valuation of drip subsidy programs suggests that the expansion of drip use in Pakistan could have a transformative effect on the range of production. Although aspirations for citrus and other fruits in rainfed Attock and Chakwal correspond closely with current crops, the dreams of expanding vegetable and melon cropping in Chakwal and Layyah, or chili farming and vegetable gardens in Sahiwal, do not map onto the current agricultural landscape.

There is a clear linkage from drip program design to the question of the role of wheat and the programs that focus on wheat self-sufficiency (e.g., Farooq and Iqbal 2000) in Pakistan. For years, the inefficiencies and expense of the wheat procurement program has been of concern for many observers; results here suggest that an appropriate balance of subsidy and expansion of coverage could aid in making a transition away from a dependence on wheat production more successful, with the potential to expand the range of high-value output. To this point, efforts to diversify agricultural production have paled compared with the emphasis on food security via production of wheat, but part of a pathway out of this focus is supported by the results here.

Certainly, these stated aspirations are as subject to hypothetical bias as the findings of any nonbinding experiment, and, in the case of Sahiwal, the lack of local experience with drip might lead one to view the broad range of aspirations as being uncalibrated, although the extent of the higher-valued agriculture in the district may help bring more reality into their aspirations. Additionally, the study used a cross-sectional (single time period) data set from a nonrepresentative sample, and so there clear limitations on the types of inferences that can be made. One cannot make any inference about how drip systems could actually change farm performance or structure, nor can one infer adoption rates that could follow particular incentive structures. These baseline data do, however, allow identification of how the best available sample of drip system adopters in Pakistan think about farming with drip compared with their nonadopting peers, providing some compelling evidence that successful promotion of drip irrigation via programs like PIPIP could have a transformational impact on Pakistan's agricultural economy.

Conclusions

This study has provided some evidence on the potential for drip-irrigation systems to transform the agricultural landscape in Punjab, Pakistan. A discrete choice experiment was undertaken framed around the hypothetical subsidized purchase of a drip-irrigation system in four districts within Punjab, a region where an existing subsidy program is helping to augment currently low levels of adoption of the technology. The nonrepresentative sample of adopters and nonadopters in the study districts identified a clear increase in valuation of drip systems among those who had adopted drip in recent years, possibly suggesting that farmers may be unaware of its opportunities or the benefits that may accrue. A possible counternarrative is that those who value drip systems have already adopted, implying a costly path to further expansion and highlighting the importance of a follow-up (panel) evaluation. It was also observed that aspirations for cropping systems under drip were better predictors of the valuation of drip systems than were current cropping patterns, implying that a different agricultural landscape might reasonably emerge under improved adoption of drip.

Aspirations differed across the different agroecological zones and water regimes captured by the study, with specific ambitions, such as for enhanced fruit and nut cropping in the rainfed districts of Attock and Chakwal, occurring when greater levels of experience with drip were observed in the study sample. In addition, there was a wider range of envisioned crops under drip in canal-fed Sahiwal, where very little experience with drip was observed in the study sample, but where it is also suspected that conditions with regard to market access for higher-valued production are good in that district. Aspirations to substitute wheat for fruit and vegetables were associated with higher sensitivity to the subsidy level, whereas aspirations to expand wheat were associated with a higher sensitivity to the area covered by the drip system; together, these imply a degree of control over the extent of wheat production in the landscape via careful design of the drip subsidy program. Although the penetration of drip irrigation is not sufficient enough yet to draw inferences from a representative sample, these results suggest a number of ways through which drip irrigation may transform Pakistan's agricultural landscape and for enhancing its adoption.

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Supplemental Data

Tables S1–S8 are available online the ASCE Library (www.ascelibrary.org).

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